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Guided Ground Transport
Queen's University
at Kingston, Ontario

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# RAILWAY LINEHAUL ENERGY INTENSITY: Development of an Enhanced Train-Handling Module for the AAR Train Energy Model

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Un sommaire en français de ce rapport est inclus avant la Table des matières.

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16. Abstract

This report is the third in a series of CIGGT reports on Railway Linehaul Energy Intensity sponsored by Transport Canada. The first report (CIGGT Report #80-15, "Railway Linehaul Energy Intensity: An Analysis Leading to the Design of a Train Simulation Software Package, 1980") made recommendations on the design of a realistic train handling model. Train handling techniques can have significant effects on train energy consumption. This report presents a method of integrating the recommended train-handling simulation module into an existing train simulation model, namely the AAR Train Energy Model.

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16. Résumé

Ce rapport est le troisième d'une série publiée par le Canadian Institute of Guided Ground Transport (CIGGT) sur la simulation de la dépense d'énergie des trains, programme parrainé par Transports Canada. Le premier de ces rapports, le n° 80-16 du CIGGT, intitulé "Railway Linehaul Energy Intensity: An Analysis Leading to the Design of a Train Simulation Software Package, 1980", avait formulé des recommandations concernant l'étude d'un modèle de simulation de la conduite des trains qui soit réaliste. On sait que les caractéristiques de conduite influent considérablement sur la consommation d'énergie. Ce rapport explique une méthode par laquelle le module recommandé sur la simulation des paramètres de conduite d'un train peut être intégré dans le programme informatique existant, à savoir le modèle de simulation de la dépense d'énergie des trains élaboré par l'Association of American Railroads.

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# SUMMARY

Many applications of a train energy model involve long train runs where it is unacceptable to use predefined or interactive control settings for the locomotive. It is necessary to have an automatic selection of appropriate brake and throttle settings in response to location, actual train speed and desired train speed. Also, train-handling differences can have significant effects on a train's energy consumption. Thus it is desirable to provide flexibility in the automatic mode so that a range of acceptable train-handling techniques can be implemented and tested.

This report outlines a method of integrating a realistic train-handling simulation module into an existing computer program. The host model is the Train Energy Model (TEM) being developed by the Association of American Railroads (AAR).

The train-handling module is designed to obey posted speed restrictions in a manner determined by the type of terrain involved and the type of train involved, while offering sensitivities to a range of train-handling techniques.

The new code will be completely contained in the two existing programs (i.e., PRE and TEM). Program PRE contains profile preprocessors which need to be run only once for each track file or driver characteristic. The additions to program TEM include preprocessors which depend on run time information and a replacement control module. Two modules are added to program PRE, one to compress the track data file and one to provide driver characteristics.

The changes to the main simulation program, TEM, involve the addition of two preprocessors and the replacement of the control algorithm. TEM now prompts the user to specify the type of driver being simulated. Any of three predefined driver types can be utilized, as well as any user-created driver characteristic files. Sensitivity analyses using all three predefined driver types can be made within the same TEM run, generating three output files.

# SOMMAIRE

De nombreuses applications du modèle de simulation de la dépense d'énergie des trains concernent des trajets de grande longueur qui interdisent des réglages prédéfinis ou interactifs des commandes. On cherche donc à automatiser les réglages de freinage et de marche en fonction du terrain et de l'allure tant réelle que voulue. Par contre, les écarts dans les paramètres de conduite du train peuvent influer considérablement sur la consommation énergétique. Il faut donc prévoir une automatisation souple pouvant simuler toute une gamme de paramètres dans la mesure où ils sont considérés comme acceptables.

Ce rapport explique une méthode par laquelle un module permettant de simuler les paramètres de conduite d'un train avec beaucoup de réalisme peut être intégré dans le programme informatique existant, à savoir le modèle de simulation de la dépense d'énergie des trains (TEM) élaboré par l'Association of American Railroads.

Ce module est conçu pour respecter les consignes de vitesse d'une manière variable selon le profil de la voie et le type de train considérés, et en fonction des paramètres de conduite choisis dans une fourchette plus ou moins étendue.

Cette nouvelle séquence est complètement intégrée dans les deux programmes existants (PRE et TEM). Le programme PRE renferme des préprocesseurs profil de voie que l'on ne doit faire fonctionner qu'une seule fois par tronçon de voie simulé ou par jeu de paramètres de conduite retenu. Les changements apportés au programme TEM ont été l'adjonction de deux préprocesseurs dont le fonctionnement dépend des informations sur les temps de parours, et le remplacement de l'algorithme de commande. Les deux modules ajoutés servent, l'un à condenser les données sur la voie, l'autre à fournir les paramètres particuliers de conduite.

Ainsi modifié, le programme TEM demande à l'utilisateur de spécifier les paramètres de conduite que celui-ci veut voir simulés et qui s'inscrivent dans trois ensembles distincts et prédéfinis; l'utilisateur a toutefois l'option de créer ses propres fichiers sur les paramètres à simuler. Enfin, des analyses de sensibilité peuvent être faites, en simulant les trois ensembles prédéfinis, à tour de rôle, au cours d'un même passage-machine du programme TEM, obtenant de la sorte trois fichiers distincts.

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# 1. INTRODUCTION

Many applications of a train energy model involve long train runs where it is unacceptable to use predefined or interactive control settings for the locomotive. It is necessary to have an automatic selection of appropriate brake and throttle settings in response to location, actual train speed and desired train speed. Also, train-handling differences can have significant effects on a train's energy consumption. Thus it is desirable to provide flexibility in the automatic mode so that a range of acceptable train-handling techniques can be implemented and tested.

This report outlines a method of integrating a realistic train-handling simulation module into an existing computer program. The host model is the Train Energy Model (TEM) being developed by the AAR.[1]

A previous review of the model[2] noted some deficiency in the train-handling module. English et al. made recommendations on the structure of a train-handling module in their 1980 report.[3] The modules outlined in this report provide an implementation of those recommendations.

The train-handling module is designed to obey posted speed restrictions in a manner determined by the type of terrain involved and the type of train involved, while offering sensitivities to a range of train-handling techniques.

One principal departure from the original recommendations is in the area of braking. The original report recommended a very simplified braking representation on the basis that the added complexity has a minor impact on energy consumption. However, the envisaged applications of the new control module include a train dynamics analyzer in addition to a train energy model. Detailed representation and realistic implementation of train air brakes are necessary requirements of a train dynamics simulation model. Thus, more detailed braking strategies are built into the present modules.

Once implemented, the train-handling module will incorporate the following features:

- elimination of overspeed problems which exist in the present version of TEM
- variation of train-handling techniques across three predefined types

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[1] W.F. Drish, Jr., *Train Energy Model User's Manual Version 1.0*, Report No. R-625, AAR Technical Centre, August 1986.

[2] J.D. Young, G.W. English, H. Boumeester, *Railway Linehaul Energy Intensity: Review of AAR Train Energy Model and Validation Data Availability*. CIGGT Report No. 85-7, TP 7365E, October 1985.

[3] G. W. English, J.D. Young, H. Boumeester, C. Schwier, M.D. Roney, P.M. Bunting, *Railway Linehaul Energy Intensity: An Analysis Leading to Design of a Train Simulation Software Package*. CIGGT Report No. 80-15, February 1981.

- user modification of some elements of train handling beyond the three base cases (e.g., width of speed control band, level of stretch braking).

The following section of this report outlines the changes required to TEM in order to implement the enhanced train-handling module, while Section 3 presents a description of each of the new submodules.

## 2. STRUCTURAL CHANGES TO TEM-4

The new code will be completely contained in the two existing programs (i.e., PRE and TEM). Program PRE contains profile preprocessors which need to be run only once for each track file or driver characteristic. The additions to program TEM include preprocessors which depend on run time information and a replacement control module.

### 2.1 CHANGES TO PRE

Two modules are added to program PRE, one to compress the track data file (PREPRO) and one to provide driver characteristics (TEMDRV). The modules of program PRE are illustrated in Figure 1.

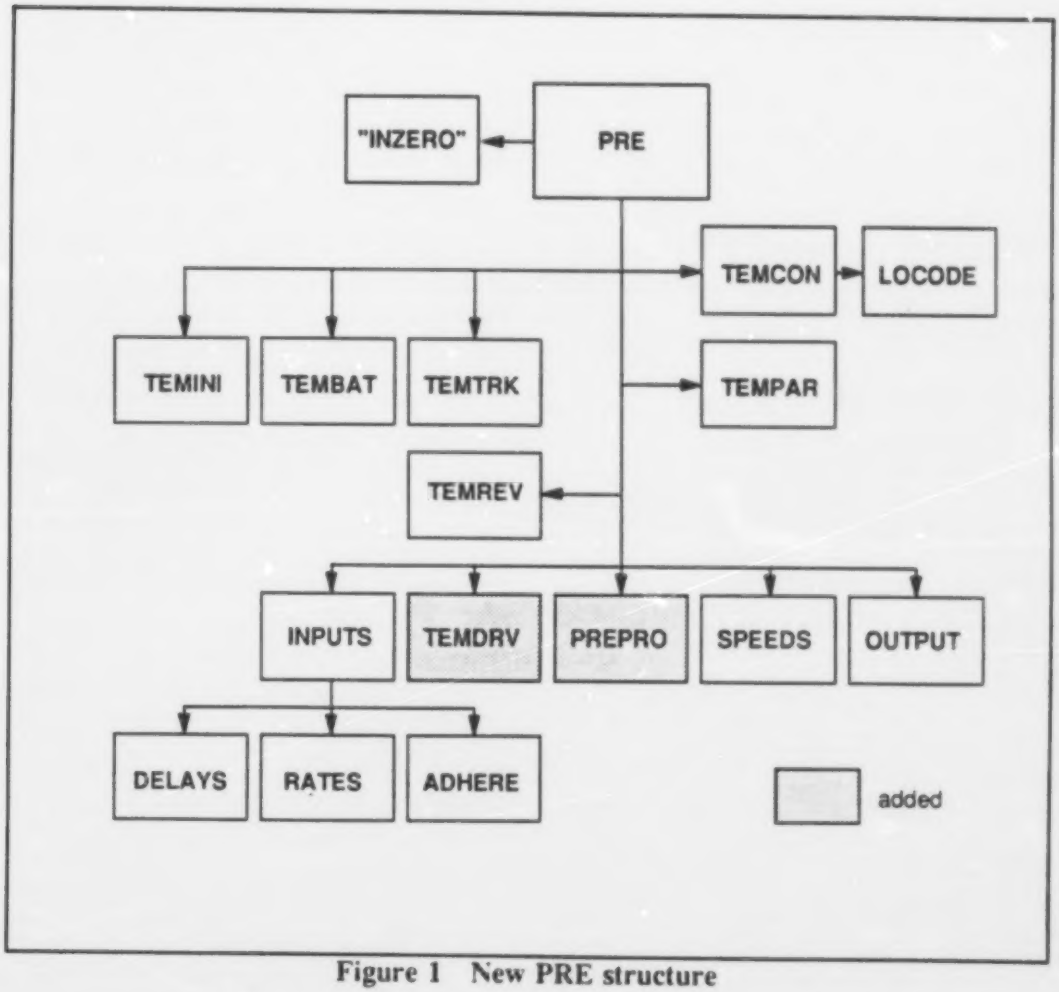


Figure 1 New PRE structure

The profile preprocessor (PREPRO) reduces the track data and produces a "crunched" track data file to be used for profile classification in TEM. The crunching operation need only be run once for a particular track file. An eighth option to the PRE operational menu has been added to allow the user to select this operation. The creation of a crunched track file is carried out if PRE is used to either build a new track file or reverse an existing track file. The track-crunching preprocessor is a subroutine of PRE. The only variable passed to it is the name of the file to be crunched.

Provision has also been made to permit specification of the type of driver to be simulated when the initialization file is created using PRE. In this regard, a ninth option has been added to the PRE operation menu to allow the user to build his own driver characteristics table. The software to do this will be contained in subroutine TEMDRV. **Figure 2** illustrates the eighth and ninth file creation options added to program PRE.

## 2.2 CHANGES TO PROGRAM TEM

The changes to the main simulation program, TEM, involve the addition of two preprocessors and the replacement of the control algorithm. TEM now prompts the user to specify the type of driver being simulated. Any of three predefined driver types can be utilized, as well as any user-created driver characteristic files. Sensitivity analyses using all three predefined driver types can be made within the same TEM run, generating three output files.

The feature flag preprocessor (called PREFEA) consolidates the crunched track data one level further (for only the track section to be simulated). It uses the crunched track data file created by the preprocessor program PRE to produce a temporary feature code file containing gradient classified track data. The prefix of the track file name is passed to the subroutine through the call statement. The subroutine uses the crunched track file to produce a temporary feature code file for only the section of track to be simulated. The starting and stopping mileposts are passed to the subroutine through the existing common block RDATA1. The train length, which is also required for the calculations, will be calculated from vehicle length data, available in the existing common block TRAIN.

The control preprocessor (known as PRECON) generates a temporary file (TEM.CMD) of control flags in order to reduce the number of look-ahead calculations performed during the simulation. It conservatively estimates look-ahead mileposts. The temporary feature codes file and data from existing common blocks RDATA1 and TRAIN are used.

The new control module will be a direct replacement for the existing subroutine ROBOT and its called routines (i.e., REFER1, SLAVE1, CREST1 AND MAXIM1). The new control module consists of three major components: the control supervisor (called SUPER), the control command processor (called CONTRL), and a look-ahead routine (called LOOK). The modules of program TEM to be replaced and those to be added are shown in **Figure 3**.

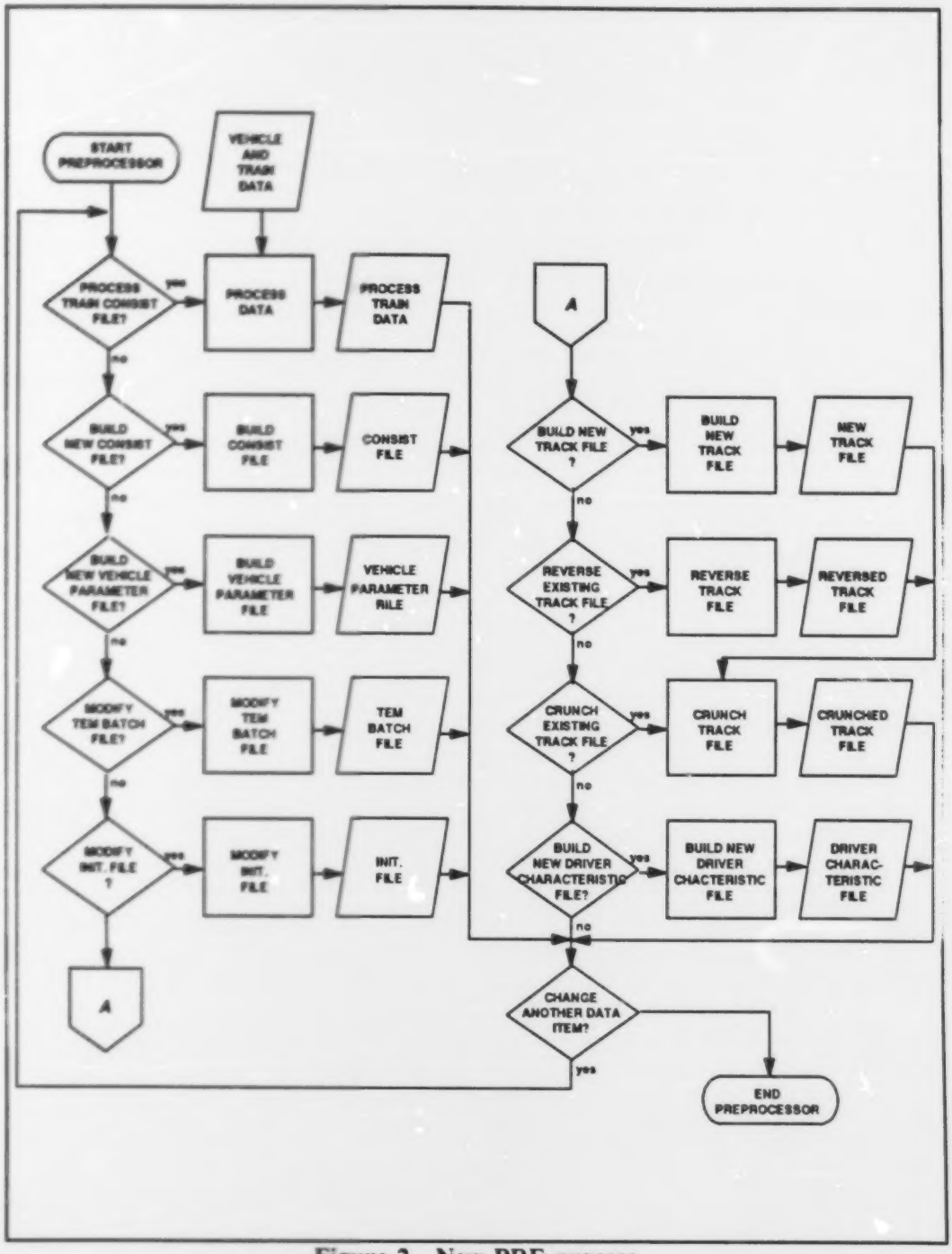


**Figure 2 New PRE process**

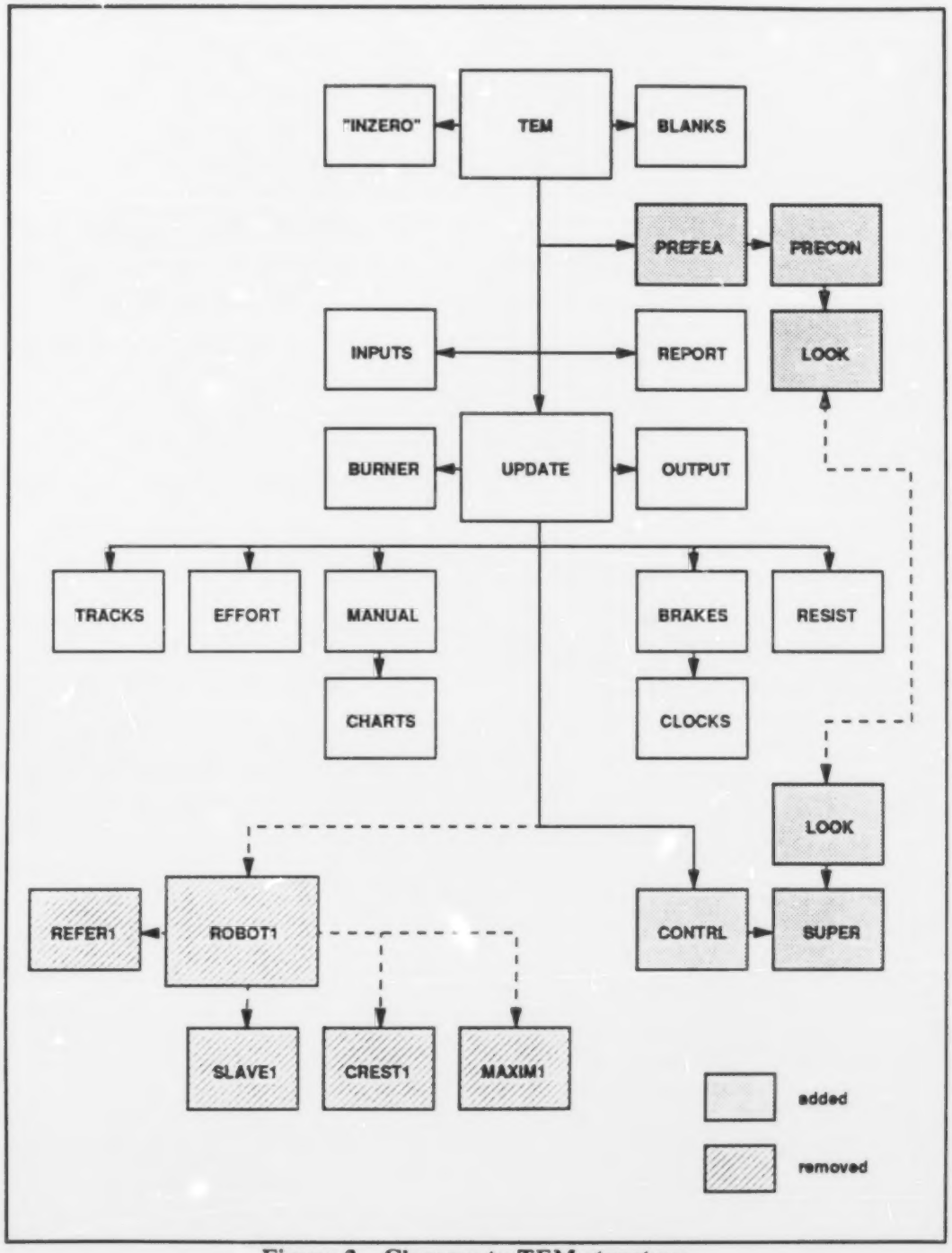


Figure 3 Changes to TEM structure

Subroutine CONTROL is the control command processor. It obtains the present milepost speed and acceleration (from the existing subroutine UPDATE through the existing common block INFORM), as well as the control target milepost, control target speed and control resource allocation from SUPER via common block CONTROL. It selects the control settings for throttle and brake settings and passes them back to TEM through existing common blocks DIESEL, QUEUES and AIR.

Subroutine SUPER is the decision-making unit of the new controller. It uses the temporary control and feature code files, driver characteristics, and data on train position and speeds. The driver characteristics are specific to the driver type being simulated and are read in from a data file. The driver type (variable DTYPE) is specified by the user and is passed from the main program through a new common block, DRIVER. SUPER passes the target mileposts and target speeds to LOOK through the common block TARGET. The control target speeds and control resource allocation are passed to the control command processor CONTROL through the common block CONTROL.

Subroutine LOOK is the look-ahead calculator for both PRECON and SUPER. A variable (NCALL) is passed to the subroutine in order to specify whether it is being used by PRECON or SUPER. It produces additional intermediate target mileposts and speeds, transferred through the common block ACTION. These form the control action cue.

The present train speed, position and acceleration are obtained from the existing subroutine UPDATE through the existing common block INFORM.

Aside from the calls to subroutines PREFEA and PRECON and the new control module, no other major modifications to TEM will be required. The execution sequence of the revised TEM is shown in **Figure 4**.

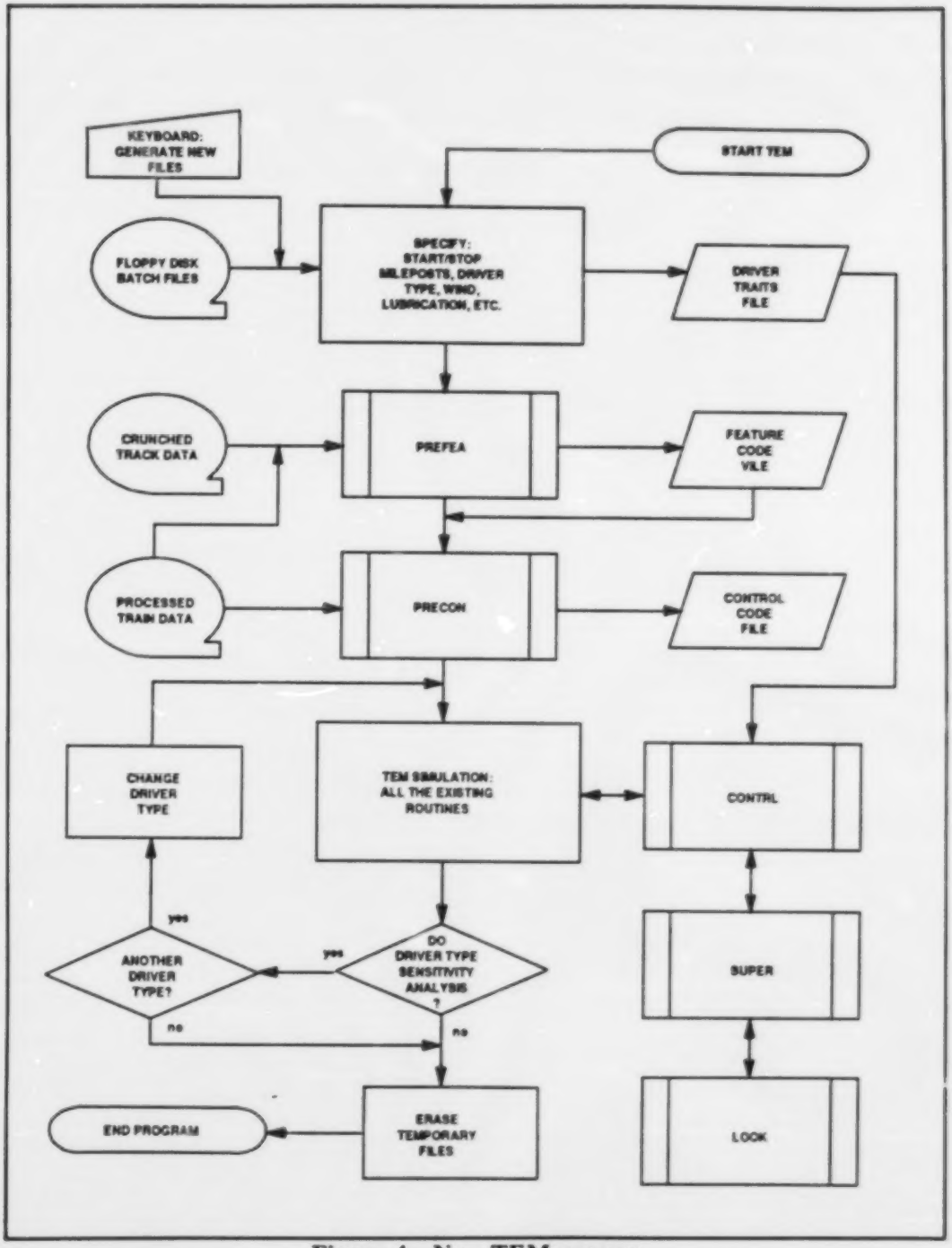


**Figure 4 New TEM process**

# 3. NEW PROGRAM MODULES

## 3.1 THE PROFILE PREPROCESSOR: PREPRO

The profile preprocessor takes the track data (either from a specified track data file or user generated in PRE) and creates a reduced or "crunched" track file. The crunched track file has segments aggregated together that are of the same gradient classification.

- **Input Data**:
  - track file:
    - footage
    - elevation
    - percent grade
    - degree of curvature
    - speed limit
    - mile post
    - station name
    - lubrication status
  - gradient table:
    - grade classifications

- **Output Data**:
  - crunched track file:
    - footage
    - gradient
    - speed limit
    - profile code

The codes for the profile are defined as follows:

| | |
|---|---|
| -2 | for severe downgrade |
| -1 | for moderate downgrade |
| 0 | for level |
| 1 | for moderate upgrade |
| 2 | for severe upgrade |

The detailed block diagram for this module is shown in Appendix A.1

## 3.2 THE FEATURE FLAG PREPROCESSOR: PREFEA

The feature flag preprocessor takes the crunched track data file produced by PREPRO and creates a new file with an additional field that defines segments of track into particular terrain types.

- **Input Data:**
  - train length
  - train weight
  - crunched track file:
    - footage
    - elevation
    - gradient
    - speed limit
    - profile

- **Output Data:**
  - feature flag file:
    - feet
    - elevation
    - gradient
    - speed limit
    - profile code
    - feature code

The codes for each feature are defined as follows:

| | |
|---|---|
| 4 | Crest |
| 3 | Knoll |
| -4 | Trough |
| -3 | Dip |

The detailed block diagram for this module is shown in Appendix A.2

## 3.3 THE CONTROL COMMAND PREPROCESSOR: PRECON

The control command preprocessor (PRECON) is designed to calculate the look-ahead mileposts at which the control supervisor must begin considering actions required to accomplish certain required train control manoeuvres.

Train control manoeuvres that require look-ahead calculations are:

- stops
- speed limit reductions
- maximum speeds at the bottoms of grades.

The control command preprocessor uses the look-ahead calculator (LOOK) to perform the initial series of calculations and to establish the look-ahead mileposts.

The look-ahead calculations are performed using nominal driver characteristics and posted speed limits as present speeds. This results in a conservative set of look-ahead mileposts that are subsequently used by the control supervisor during the actual simulation run to initiate the detailed look-ahead calculations.

- **Input data:**
  - train length and mass
  - feature flag file:
    - profile code
    - feature codes
    - speed limits and slow orders
    - stop mileposts

- **Output data:**
  - control flag file:
    - look-ahead milepost
    - target milepost
    - target speed (0.0 for a stop)

The detailed block diagram for this module is shown in Appendix A.3

### 3.4 LOOK-AHEAD CALCULATOR: LOOK

The look-ahead calculator (LOOK) is designed to calculate the series of mileposts and speeds that the controller should try to match in order to accomplish the overall required control manoeuvre (e.g., stopping the train). These mileposts and speeds (called "control target mileposts" and "speeds") are loaded into a control action cue to be passed back to the control supervisor or control preprocessor (**Figure 5**).

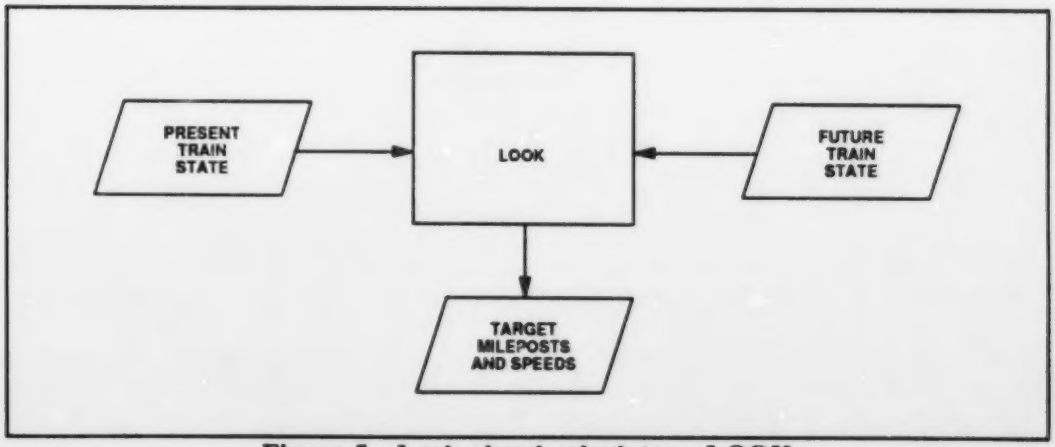


**Figure 5 Look-ahead calculator: LOOK**

The look-ahead calculator performs a backwards calculation from the target milepost in order to determine the action milepost where the manoeuvre needs to be initiated. Because there may be changes in track profile or significant track features (such as dips or knolls) between target milepost and action milepost, the look-ahead calculator must be able to accommodate these. This is done by treating each track feature separately and determining a target speed at the transition between each feature. The target speed at the beginning of each track feature is calculated

knowing the target speed at the end of the feature, the profile of the track section, the overall manoeuvre and the prescribed acceleration or deceleration profiles.

The calculated speeds are compared against the speed limits to ensure that overspeeding does not occur. The acceleration and deceleration rates as prescribed by the terrain type, the driver characteristic, the train capability and any special terrain features are also checked for limits.

When the backwards executing calculation has reached the point where the speed is equal to the present speed, control is returned to the calling subroutine with the filled-in control action cue.

- **Input data**:
  - train length and weight
  - feature code file:
    - profile
    - feature code
  - driver characteristics table:
    - deceleration rates
    - speed and acceleration bands
  - from SUPERVISOR:
    - present train milepost and speed
    - target milepost and target speed

- **Output data**:
  - control action cue:
    - control target mileposts
    - control target speeds

The detailed block diagram for this module is shown in Appendix A.4

### 3.5 CONTROL SUPERVISOR: SUPER

The control supervisor (SUPER) acts as the decision-maker of the controller. The control decisions are based on terrain profiles and features, the required train manoeuvres, and the recommended guidelines for train-handling (**Figure 6**).

The terrain profile and features are communicated to the control supervisor by the profile and feature flags that have been preset in the feature flag file. The required train manoeuvres are calculated by the look-ahead calculator and are stored in the control action cue.

The recommended guidelines are based on those described in *Track Train Dynamics Guidelines to Improve Freight Train Performance*.[4]

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[4] *Track Train Dynamics to Improve Freight Train Performance*, 2nd Ed. AAR Report R-185, 1979

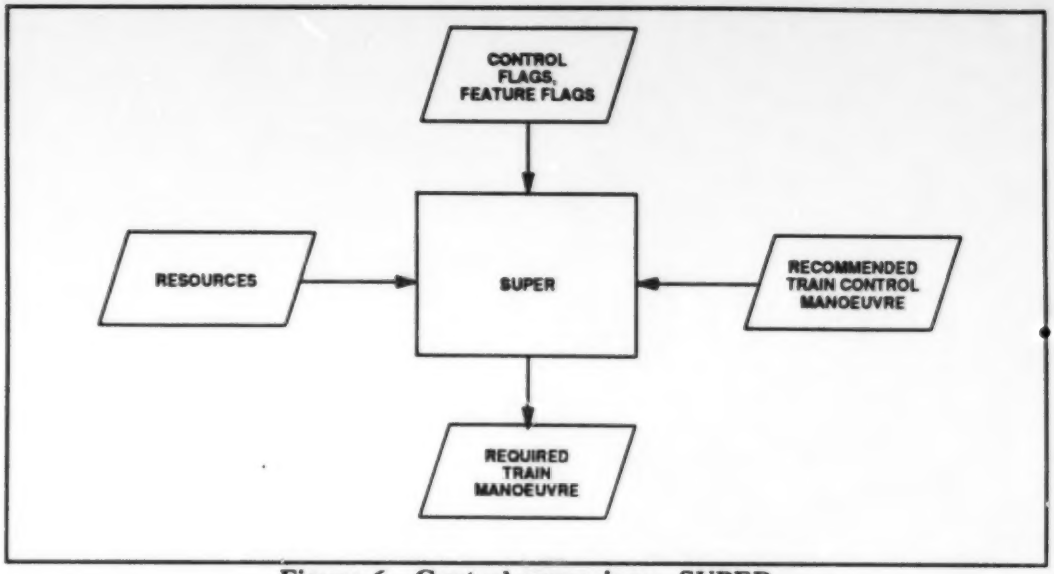



**Figure 6 Control supervisor: SUPER**

The control supervisor also initiates a detailed look-ahead calculation (by the look-ahead calculator) when it determines an upcoming change in manoeuvre. This is signalled by a flagged milepost in the control flag file. The look-ahead calculations fill the control action cue from which the control supervisor gets the required train manoeuvres.

Based on the terrain, manoeuvre, train state, and driver characteristic, the control supervisor then allocates the train control resources to the control command processor (CONTRL) according to the appropriate guidelines.

- **Input data**:
  - feature code file:
    - profile
    - feature code
  - control flag file:
    - look-ahead mileposts
    - target mileposts
    - target speeds
  - driver characteristics
    - deceleration
    - speed and acceleration bands
  - control action cue:
    - control target mileposts
    - control target speeds

from UPDATE:
present milepost
present speed
present acceleration

- **Output data**:
  to LOOK (when at a look-ahead milepost):
  target mileposts
  target speeds
  to CONTRL:
  control target mileposts
  control target speeds
  train control resource allocation

The detailed block diagram for this module is shown in Appendix A.5

### 3.6 CONTROL COMMAND PROCESSOR: CONTRL

The control command processor (CONTRL) uses the train control resources allocated to it by the Supervisor to accomplish the dictated manoeuvre (**Figure 7**). The train control resources may consist of:

- throttle
- dynamic brakes
- automatic air brakes
- locomotive independent air brakes

Because the nature of the control is dictated by the train-handling guidelines, some manoeuvres may be done without using all of the available controls (i.e., slow down using only the dynamic brakes to let the slack run in). The control command processor is designed to use whatever resources have been allocated to the present manoeuvre.

The control command processor has the capability of calling the supervisor and demanding further resources to accomplish a task if it finds that it has not been allocated enough to complete the task.

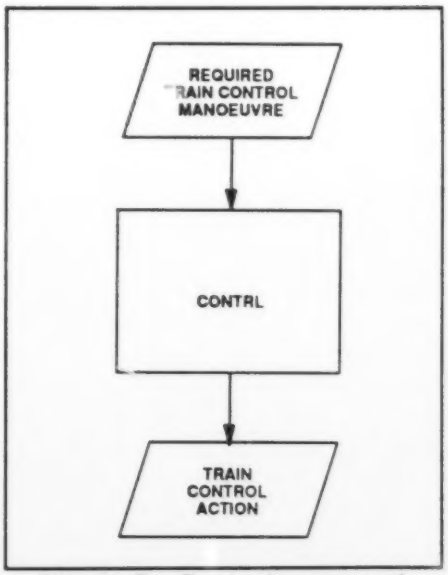



**Figure 7 Control command processor: CONTRL**

At the end of each TEM simulation step, execution returns to the control command processor, which then evaluates the status of the current train state against the target train state. If the control is behaving normally, the control command processor makes the required control adjustments and returns to TEM for another step. If the present control action is complete, or if the simulation is in a constant look-ahead phase, the control command processor transfers execution to the supervisor for the necessary action.

- **Input data**:
  - from UPDATE:
    - present milepost
    - present speed
    - present acceleration
  - from SUPER:
    - control target milepost
    - control target speed
    - train control resource allocation

- **Output data**:
  - to UPDATE:
    - control settings for throttle and brakes

The detailed block diagram for this module is shown in Appendix A.6

# 4. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that it is feasible to interface with the existing train energy model (TEM), a train-handling module which will provide locomotive control settings. This module will provide a capability for user-specification of different train-handling objectives while meeting speed limits and stop locations input by the user.

It is recommended that the train-handling modules outlined here be implemented in a new version of the TEM.

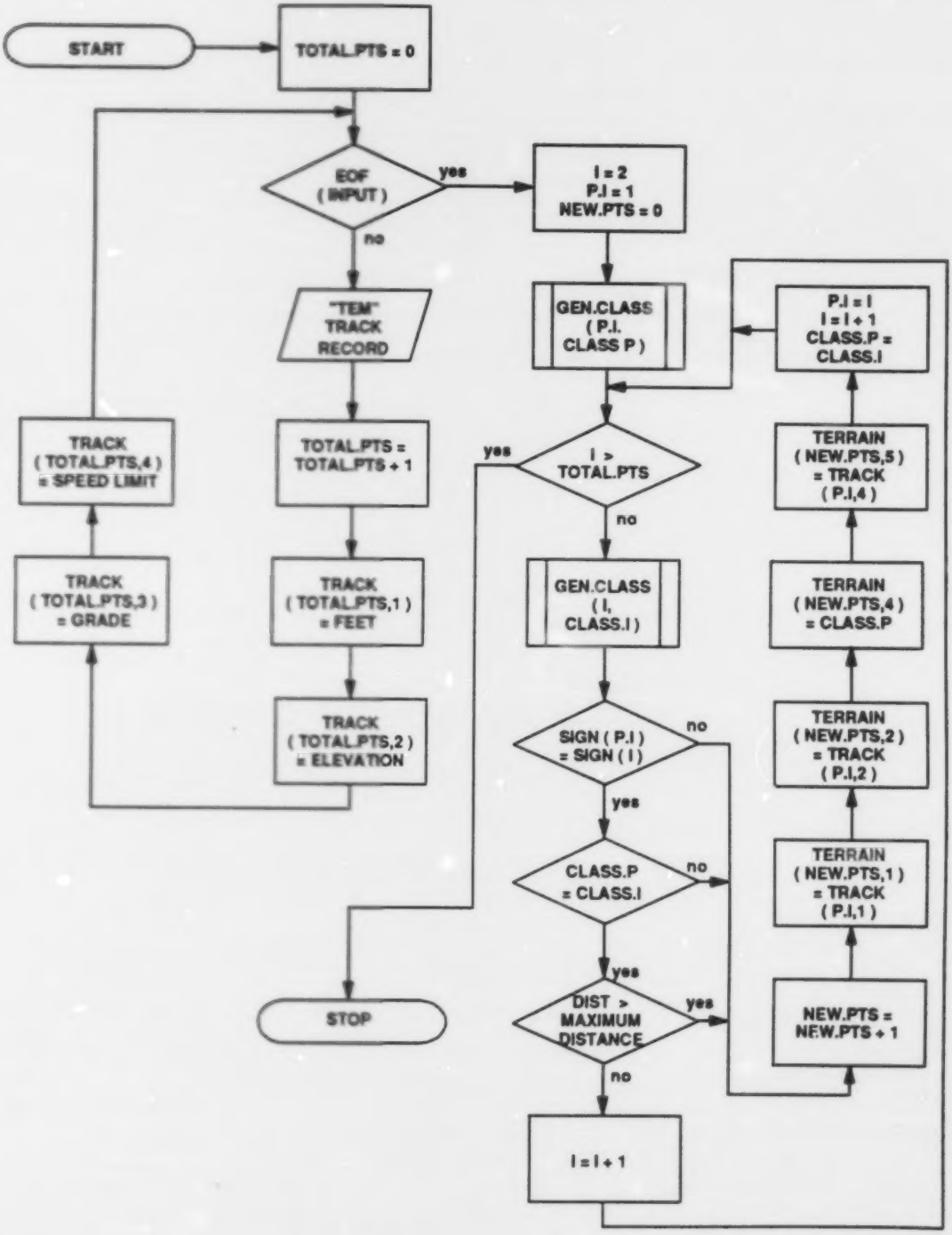
# APPENDIX A

## DETAILED BLOCK DIAGRAMS

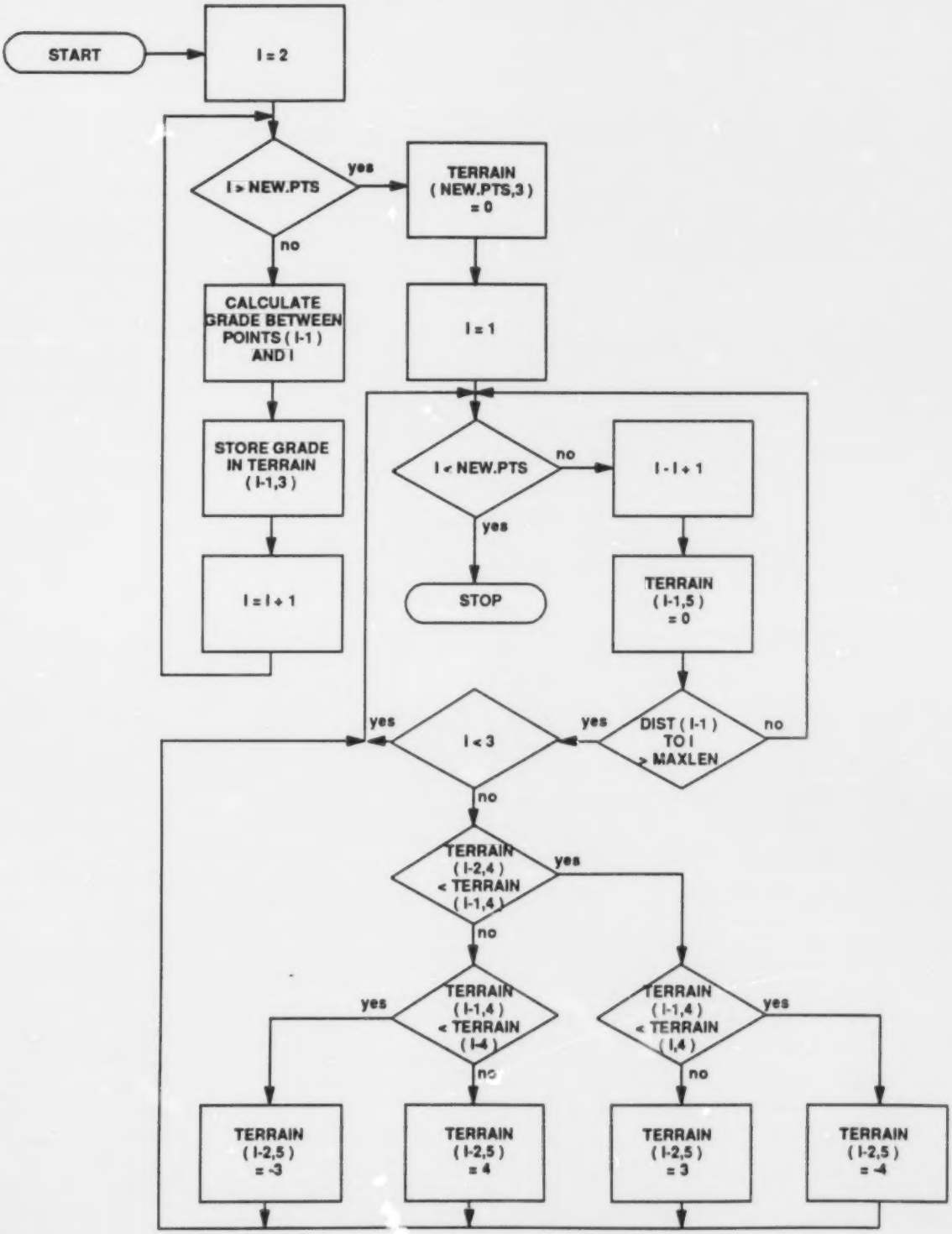
This appendix provides detailed block diagrams and/or logic flow charts for each of the new program modules required to implement the train-handling system outlined in this report. The modules are presented in the following order:

A.1: Profile Preprocessor: PREPRO
A.2: Feature Flag Preprocessor: PREFEA
A.3: Control Command Preprocessor: PRECON
A.4: Look-Ahead Calculator: LOOK
A.5: Control Supervisor: SUPER
A.6: Control Command Processor: CONTRL

## A.1 Profile Processor: PREPRO

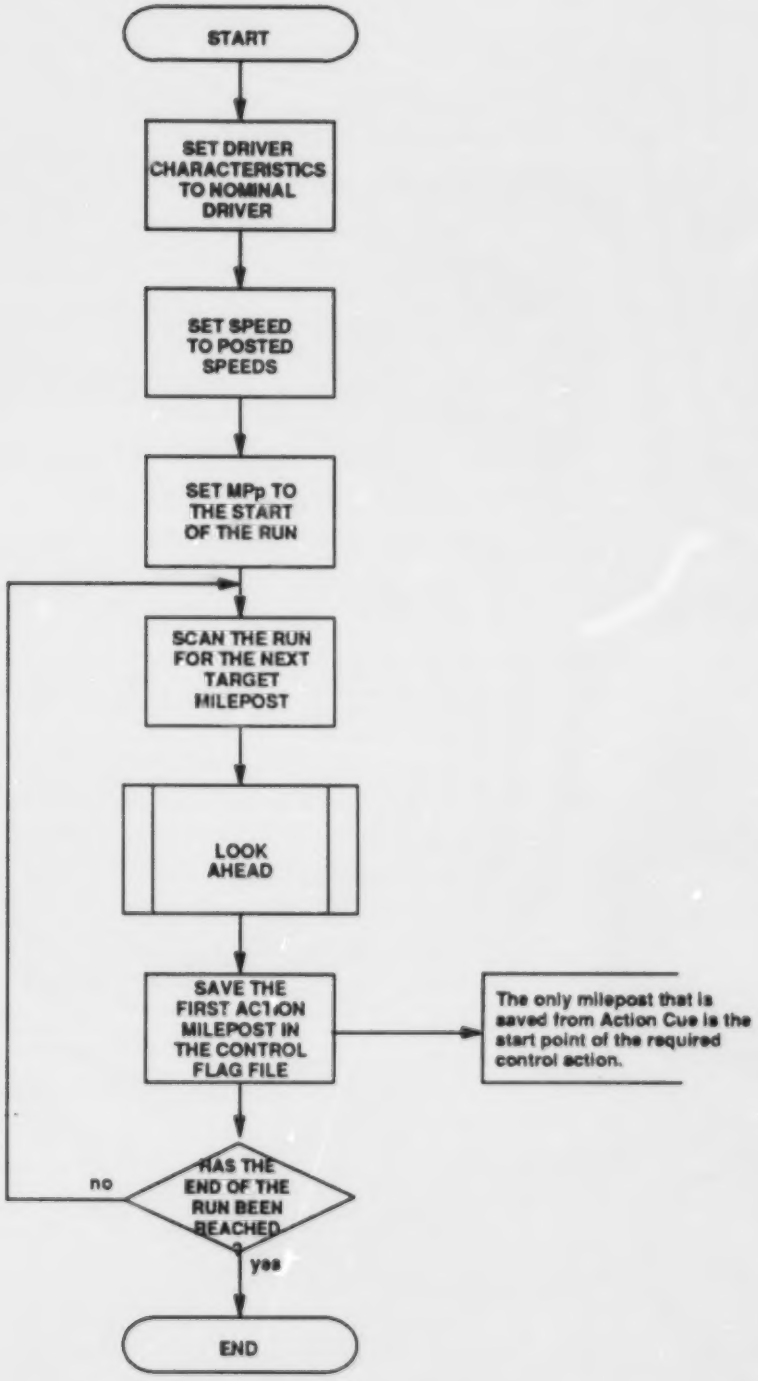


## A.2 Feature Flag Preprocessor: PREFEA

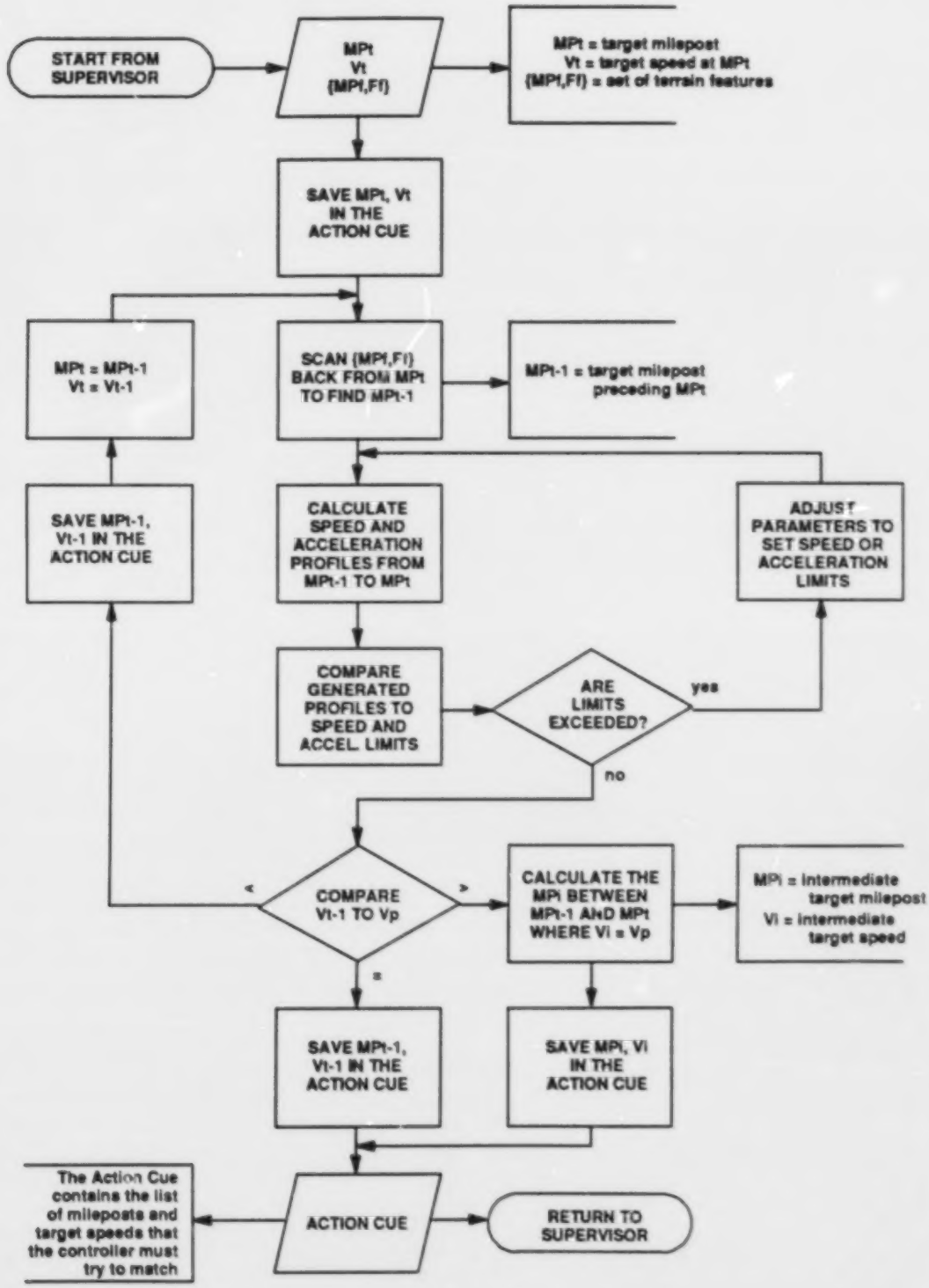



A.2

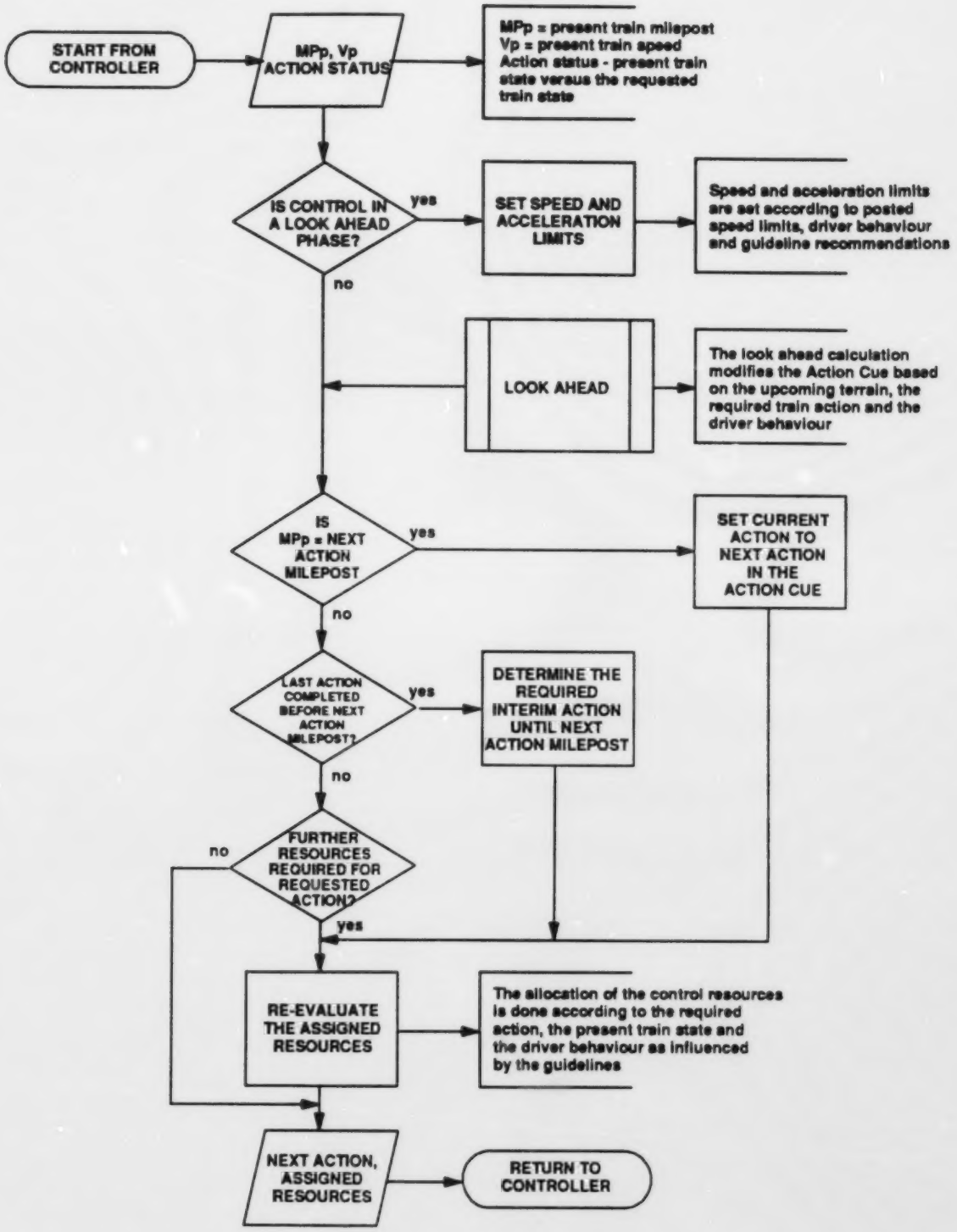
## A.3 Control Command Preprocessor: PRECON


START
SET DRIVER CHARACTERISTICS TO NOMINAL DRIVER
SET SPEED TO POSTED SPEEDS
SET MPp TO THE START OF THE RUN
SCAN THE RUN FOR THE NEXT TARGET MILEPOST
LOOK AHEAD
SAVE THE FIRST ACTION MILEPOST IN THE CONTROL FLAG FILE
The only milepost that is saved from Action Cue is the start point of the required control action.
HAS THE END OF THE RUN BEEN REACHED ?
no
yes
END

## A.4 Look-Ahead Calculator: LOOK


START FROM SUPERVISOR
MPt
Vt
{MPI,FI}
MPt = target milepost
Vt = target speed at MPt
{MPI,FI} = set of terrain features
SAVE MPt, Vt IN THE ACTION CUE
MPt = MPt-1
Vt = Vt-1
SCAN {MPI,FI} BACK FROM MPt TO FIND MPt-1
MPt-1 = target milepost preceding MPt
SAVE MPt-1, Vt-1 IN THE ACTION CUE
CALCULATE SPEED AND ACCELERATION PROFILES FROM MPt-1 TO MPt
ADJUST PARAMETERS TO SET SPEED OR ACCELERATION LIMITS
COMPARE GENERATED PROFILES TO SPEED AND ACCEL. LIMITS
ARE LIMITS EXCEEDED?
yes
no
<
COMPARE Vt-1 TO Vp
>
=
CALCULATE THE MPI BETWEEN MPt-1 AND MPt WHERE Vi = Vp
MPi = intermediate target milepost
Vi = intermediate target speed
SAVE MPt-1, Vt-1 IN THE ACTION CUE
SAVE MPi, Vi IN THE ACTION CUE
The Action Cue contains the list of mileposts and target speeds that the controller must try to match
ACTION CUE
RETURN TO SUPERVISOR

## A.5 Control Supervisor: SUPER


START FROM CONTROLLER
MPp, Vp ACTION STATUS
MPp = present train milepost
Vp = present train speed
Action status - present train state versus the requested train state
IS CONTROL IN A LOOK AHEAD PHASE?
yes
SET SPEED AND ACCELERATION LIMITS
Speed and acceleration limits are set according to posted speed limits, driver behaviour and guideline recommendations
no
LOOK AHEAD
The look ahead calculation modifies the Action Cue based on the upcoming terrain, the required train action and the driver behaviour
IS MPp = NEXT ACTION MILEPOST
yes
SET CURRENT ACTION TO NEXT ACTION IN THE ACTION CUE
no
LAST ACTION COMPLETED BEFORE NEXT ACTION MILEPOST?
yes
DETERMINE THE REQUIRED INTERIM ACTION UNTIL NEXT ACTION MILEPOST
no
FURTHER RESOURCES REQUIRED FOR REQUESTED ACTION?
no
yes
RE-EVALUATE THE ASSIGNED RESOURCES
The allocation of the control resources is done according to the required action, the present train state and the driver behaviour as influenced by the guidelines
NEXT ACTION, ASSIGNED RESOURCES
RETURN TO CONTROLLER

## A.6 Control Command Processor: CONTRL